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ABSTRACT

A vane pump loop was used to determine the lubricating ability as well as thermal and shear degradation of some polyphenyl ethers and superrefined mineral oils. Experimental conditions included 250 psig (1.72×10^6 N/m^2) pump pressure, 425° F (219° C) fluid temperature at the pump inlet, 600° F (316° C) fluid temperature at the heater outlet, 1.73×10^4 m/hr surface velocity and an inert cover gas (nitrogen). Low vane wear was obtained with a 77 centistoke (100° F) (38° C) napthenic mineral oil and two naphthenic-paraffinic blends. Higher wear was obtained with a 15 centistoke (100° F) (38° C) paraffinic mineral oil, a four and a five ring polyphenyl ether, and a modified polyphenyl ether (C-ether).

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SUMMARY

A vane pump loop was used to determine the lubricating ability as well as thermal and shear degradation of some polyphenyl ethers and superrefined mineral oils. Experimental conditions in most cases were 250 psig (1.72×10^{6} N/m^{2}) pump pressure, 425° F (219° C) fluid temperature at the pump inlet, 600° F (316° C) fluid temperature at the heater outlet, 1600 rpm pump speed, 1.73×10^{4} meters per hour surface velocity, 0.5 gpm (3.16×10^{-5} m^{3}/sec) flow rate, 150 hour test duration and an inert cover gas (nitrogen). The pump, including the vanes, was made of CVM M-50 tool steel.

Low vane wear was obtained with a 77 centistoke (100° F, 38° C) superrefined naphthenic mineral oil. Higher vane wear was obtained with a 15 centistoke (100° F, 38° C) superrefined paraffinic mineral oil. Two intermediate viscosity blends of these fluids yielded low vane wear. High vane wear was obtained with a four and a five ring polyphenyl ether and a modified polyphenyl ether (C-ether).

Vane wear was substantially lower and more reproducible in naphthenic oils which were vacuum degassed at 250° F (121° C) than in those which were degassed at 75° F (24° C). The higher temperature procedure resulted in residual dissolved oxygen concentrations of less than 2 ppm by weight while the 75° F (24° C) vacuum degassing produced a range of oxygen concentration from 2 to 20 ppm.

The additive response of the naphthenic oil to a paraffinic resin antiwear additive (2.25 wt. % addition) appeared to vary with the degassing procedure. Because of the low vane wear observed with the more thoroughly degassed oil, it was difficult to detect further improvements attributable to the resin; on the average, however, lower vane wear was obtained in these oils when they contained the resin than when they did not. Reduction in vane wear was more apparent in oils which had been degassed at 75° F (24° C). Vane wear was consistently and significantly lower in these oils when they contained the resin addition. The resin was not effective in naphthenic oils which were not degassed at all.

The mineral oils and mineral oil blends showed no significant change in fluid properties. The three polyphenyl ethers produced large quantities of insolubles but viscosities and neutralization numbers were essentially unchanged.

INTRODUCTION

Supersonic aircraft and aerospace vehicles have created needs for hydraulic fluids and lubricants capable of operating without appreciable fluid degradation from 400° to 600° F (204° to 316° C) (ref. 1). Superrefined mineral oils (refs. 2 and 3), polyphenyl ethers (ref. 4), and a modified polyphenyl ether (ref. 5) have been reported as possible candidates.

Piston and vane pump loops have been used by many investigators (refs. 3, and 6 to 9), for fluid evaluations. The vane pump has the advantages of simple construction, ease of maintenance, and high tolerance for fluid contamination. In addition, the vane-on-cam-ring sliding contact provides a sensitive technique for wear measurement.

For years synthetic polymers such as the polymethacrylates and polybutenes have been added to lubricants to improve their viscosity-temperature characteristics. Experiments with these polymer-modified oils have revealed an interesting side effect. Okrent (ref. 10) and Savage (ref. 11) observed that polymer-modified mineral oils gave lower wear and friction in automobile connecting-rod bearings than straight mineral oils of the same low shear viscosity. One of the theories for this reduction in wear is polymer surface adsorption producing a high viscosity film at the surface (ref. 10).

Several problems are involved using high molecular weight polymers (>10 000 MW) as oil additives. First, these polymers are subject to chain scission with its resulting permanent viscosity loss. Secondly, oils with synthetic polymer additives are non-Newtonian and subject to temporary viscosity losses due to shear thinning (ref. 10). Finally, solubility and volatility problems can be encountered with some base stocks. Both types of viscosity loss are very pronounced in modern applications involving high temperature and high shear rates.

Recently a high molecular weight (1700) superrefined paraffinic resin has become available (ref. 12). This resin consists of long chain paraffinic hydrocarbons and is reported to be Newtonian and shear stable. Klaus, et al. (ref. 13) have blended a 4500 centistoke (100° F, 38° C) resin with a superrefined naphthenic white oil. An addition of 2 to 3 weight percent resin has yielded 20 percent reductions in wear scar diameter in Shell four ball tests at 4 kilogram loads. Grozek (ref. 14) has found that compounds containing long methylene chains, which are similar to the resins, are preferentially adsorbed on some metal surfaces from lower molecular weight solvents. Therefore, it is possible to get an antiwear effect with the resin without the attendant problems involved when using synthetic polymer additives.

A second beneficial effect may result if resin additives do preferentially adsorb on bearing surfaces producing a viscous surface film. Dissolved oxygen has been found to be detrimental in vane pumps; the oxygen produces high wear because of surface oxidation (ref. 15). Since surface oxidation through a lubricant film is probably diffusion con-

trolled, a viscous surface film could exclude or at least retard diffusion of oxygen to the surface.

The objectives of this investigation were:

(1) To determine the lubricating ability of some superrefined mineral oils and polyphenyl ethers by measurement of vane wear in a vane pump

(2) To determine qualitatively the resistance of the fluids to combined thermal and shear degradation

(3) To determine how the addition of a paraffinic resin affects vane wear in either a thoroughly or a partially degassed naphthenic mineral oil

(4) To determine the effect of operating viscosity on vane wear for the two fluid classes in this study

Experiments were conducted with several superrefined mineral oils, a four and a five ring polyphenyl ether and a modified polyphenyl ether (C-ether) in a high temperature vane pump loop. The pump, including the vanes, was made of consumable electrode vacuum melted (CVM) M-50 tool steel. Conditions involved in this study included a 250 psig (1.72×10^{6} N/m^{2}) pump outlet pressure, a 425° to 600° F (219° to 316° C) fluid temperature cycle, 1.73×10^{4} meters per hour surface velocity and a test duration of up to 150 hours under an inert cover gas (nitrogen).

APPARATUS

The test apparatus (fig. 1) consists of a closed loop containing a vane pump, fluid reservoir, fluid heater, heat exchanger, filters, flow meter, and associated plumbing. All apparatus is made of 304 or 316 stainless steel except the pump assembly which is made of CVM M-50 tool steel.

Inspection and parts replacement are facilitated by the simple vane pump design (fig. 2). The cam ring, rotor, vanes, and one of the pressure plates are seen in an exploded view of the pump assembly (fig. 2). The inside diameter of the cam ring is 5.72 centimeters. Static "O" ring seals are Viton (fluorocarbon) with a continuous operating limit of 450° F (232° C). The dynamic shaft seal consists of a bellows type carbon face seal in sliding contact with M-50 tool steel wear ring. A variable speed (500 to 5000 rpm) electric motor drives the pump through a coupling.

The fluid reservoir is made of stainless steel pipe and contains an immersion heater to maintain bulk fluid temperature at 425° F (219° C). Reservoir design allows in situ deaeration by vacuum pumping and heating. An inert cover gas (nitrogen) at 3 psig (2×10^{3} N/m^{2}) is maintained in the reservoir.

During a test the fluid is further heated in a 13 kilowatt industrial furnace. The furnace chamber is made of heavy wall stainless steel pipe. A thirty foot coil of 1/4 inch

stainless steel tubing is immersed in a bed of fluidized sand. The sand is the heat transfer medium and nitrogen the fluidizing agent. The oil enters the coil at about 400° F (204° C) and is heated to 600° F (316° C) during a residence time in the furnace of about 9 seconds.

The heat exchanger consists of a coil of 1/4 inch stainless steel tubing enclosed in a stainless steel shell. Water provides shell side cooling.

The filter system consists of four sintered stainless steel filters with mean pore sizes of 5, 10, 20, and 35 microns, respectively. The filters are mounted between air operated valves which are controlled by a pressure switch. Flow is directed through the filters in order of increasing pore diameter. Switching to the next coarser filter takes place when the inlet pressure to the preceding filter exceeds 50 psig (3.4×10^{4} N/m^{2}).

Instrumentation consists of thermocouples, pressure transducers, and a turbine flow meter. Fluid temperature is maintained constant at the furnace outlet and in the reservoir. Automatic shutdown is incorporated in the system in case of a malfunction. An automatic fire extinguishing system is also included.

PROCEDURE

All lines are thoroughly cleaned, assembled, and purged with nitrogen. Six liters of the experimental fluid are degassed in situ after which the reservoir is backfilled with nitrogen. Vanes are weighted on an analytical balance which is accurate to 0.1 milligram. The pump is then assembled and leak tested. A new set of vanes is used for each test.

After loop assembly, the experimental fluid is heated to 250° F (121° C) in the reservoir. The pump is started at low speed and the fluid is cycled through the bypass back into the reservoir until bulk fluid temperature reaches 425° F (219° C). The fluid is then diverted through the rest of the system and pressure, temperature, flow rate, and speed conditions are set.

Normally, experiments are terminated at 50 and 150 hours for pump disassembly, inspection, vane wear measurement and fluid sample analysis. Experimental conditions, unless otherwise noted, were as follows:

(1) 250 psig (1.72×10^{6} N/m^{2}) pump outlet pressure
(2) 600° F (316° C) fluid furnace outlet temperature
(3) 425° F (219° C) bulk fluid and pump-inlet temperature
(4) 0.5 gpm (3.16×10^{-5} m^{3}/sec) flow rate
(5) 1600 rpm pump speed (1.73×10^{4} m/hr surface velocity)
(6) 150 hour test duration (50 hour inspection)
(7) Inert cover gas (nitrogen)

(8) Fluids were vacuum degassed for 24 hours at 250° F (121° C)
(9) Pump and vane material was CVM M-50 tool steel

DEGASSING PROCEDURE

Preliminary experiments with the naphthenic mineral oil yielded large variations in vane wear. The initial degassing procedure called for vacuum degassing at 75° F (24° C) for 72 hours. Later, measurements by the method of Petrocelli and Lichtenfels (ref. 16) indicated that this procedure did not always reduce initial dissolved oxygen to a low level (<2 ppm). In trial degassing using this procedure, final dissolved oxygen concentrations varied from 2 to 20 ppm. For an air saturated naphthenic oil, similar to the one used in this program, a dissolved oxygen level of 43 ppm has been reported (ref. 17). This could explain the vane wear scatter since dissolved oxygen is known to cause wear in vane pumps (ref. 15).

A new degassing procedure was devised which consisted of vacuum degassing at 250° F (121° C) for 24 hours. This procedure consistently reduced dissolved oxygen concentrations to less than 2 ppm. Wear scatter for a particular fluid was greatly reduced and reproducibility of wear data was markedly improved.

RESULTS AND DISCUSSION

Experiments were conducted with a number of high temperature hydraulic fluid and lubricant candidates. These fluids, their additives, and some viscosity data appear in table I

On the basis of vane wear measurements at 50 hours, the fluids can be divided into two groups. The first group includes those fluids which yielded low vane wear ($\propto$ 1 mg/vane/50 hr test). The second group includes those fluids which exhibited rather high vane wear ($\propto$ 30 mg/vane/50 hr test).

The low wear group includes the 77 centistoke superrefined naphthenic mineral oil and two superrefined naphthenic-parrafinic mineral oil blends. The high wear group includes the 15 centistoke superrefined paraffinic mineral oil, the four ring (4P-3E) and the five ring (5P-4E) polyphenyl ether, and the modified polyphenyl ether (C-ether). Vane wear for both groups appear in figures 3 and 4.

In figure 3, vane wear using the naphthenic oil was only 3 milligrams per vane for a 150 hour experiment. Vane wear for the two mineral oil blends (fig. 4) was similar to the naphthenic oil wear at 50 hours. However, both blend experiments were terminated at about 100 hours because of equipment malfunctions not related to the fluids.

TABLE I. - EXPERIMENTAL FLUIDS

Base stock	Additives	Temperature, ^{o}F (^{o}C)		
		100 (38)	210 (99)	425 (219)
		Kinematic viscosity, cS		
Superrefined naphthenic mineral oil	Antiwear, oxidation inhibitor	77	8.1	1.50
	Antiwear, oxidation inhibitor, 2.25 wt. % paraffinic resin	84	8.7	1.59
Superrefined paraffinic mineral oil	Antiwear, oxidation inhibitor	15	3.2	0.92
	Antiwear, oxidation inhibitor, 5 wt. % paraffinic resin	20	4.0	1.05
Superrefined naphthenic (73 wt. %) paraffinic (27 wt. %) blend	Antiwear, oxidation inhibitor	45	6.1	1.30
Superrefined naphthenic (29 wt. %) paraffinic (71 wt. %) blend	Antiwear, oxidation inhibitor	22	4.2	1.02
Four ring polyphenyl ether	None	66	6.2	1.24
Five ring polyphenyl ether	None	357	13	1.88
Modified polyphenyl ether (C-ether)	Proprietary additive package	25	4.1	1.05
Superrefined paraffinic resin		4500	170	14.5

All of the experiments with the fluids in the high wear class were terminated at 100 hours or less because of fluid-related pump malfunctions (bearing failures, low volumetric efficiency because of high vane wear, or complete loss of pump pressure due to coking deposits).

As shown in figure 3, immediate high wear (25 mg/vane after 12 hr) was obtained with the 4P-3E polyphenyl ether. At test termination of 100 hours (because of low pump pressure), vane wear was 80 milligrams per vane. The 5P-4E polyphenyl ether experiment was terminated at 74 hours (because of low and erratic pump pressure). Vane wear data for the 5P-4E fluid falls on the wear curve for the 4P-3E (fig. 4).

A modified polyphenyl ether (C-ether) experiment was terminated at 32 hours because of loss of pump pressure. Inspection revealed jammed vanes due to deposits on the vanes and rotor. After cleaning the rotor slots, repeated attempts to restart the

pump were unsuccessful. The 32 hour C-ether vane wear (fig. 4) was also similar to the 4P-3E results. In fact, wear for all three polyphenyl ether type fluids could be represented by a single curve of vane wear as a function of sliding distance.

The paraffinic mineral oil, a hydrocarbon, seems to be out of place in the high wear group whose remaining members are synthetic polyphenyl ethers. The paraffinic oil describes a different wear against time curve than the polyphenyl ethers (fig. 3). The paraffinic oil has a much more gradual increase in wear compared to the immediate high wear of the polyphenyl ethers. However, at test termination of 74 hours (bearing failure), the paraffinic oil vane wear of 67 milligrams per vane has reached the 4P-3E wear level. It appears that the high wear obtained with the paraffinic oil is due to its low viscosity at 425° F (219° C) of 0.92 centistokes and not to any inferiority in chemical type when compared to the higher viscosity naphthenic mineral oil. This is discussed further in the next section.

Viscosity Effect

Bulk fluid viscosity at the test temperature of 425° F (219° C) had little effect on vane wear for the three polyphenyl ethers. Increasing the 425° F (219° C) viscosity from 1.05 to 1.88 centistokes reduced vane wear rate less than 9 percent as shown in figure 5. However, the mineral oils have a sharp transition from high to low wear in the viscosity range of 0.92 centistokes (paraffinic oil) to 1.02 centistokes (71 wt. % paraffinic - 29 wt. % napthenic blend). Wear rate of the paraffinic oil is almost 40 times that for the 71 weight percent paraffinic blend. It is unlikely that the slight chemical difference between these two fluids could be responsible for the large difference in wear rates. It appears that under the experimental conditions of this program, a 425° F (219° C) viscosity of about 1 centistoke is necessary for a mineral oil to lubricate the vane pump effectively.

Vane pumps operate in a mixed film or partial hydrodynamic regime. Both hydrodynamic and boundary lubrication are important. For fluids of a particular chemical type, vane wear plotted against viscosity appears as a step function (ref. 18). As viscosity decreases and the hydrodynamic component diminishes, vane wear increases slowly until a sharp transition to high wear occurs. This transition corresponds to a shift from predominantly hydrodynamic to predominantly boundary lubrication. This is apparently the situation with the low viscosity paraffinic oil for which high vane wear occurred relative to the other mineral oils.

Resin and Dissolved Oxygen Effects

Initial dissolved oxygen in the naphthenic mineral oil had an influence on vane wear. The influence of oxygen in the naphthenic oil with and without resin additive is shown in the statistical plot of vane wear data in figure 6. The data show the range and distribution of wear rates for two degassing procedures and these data are summarized in table II. The use of figure 6 is illustrated by the following example. In order to determine the percentage of tests with the naphthenic oil degassed at 75° (24° C) that had wear rates of 20×10^{-9} grams per meter or lower, one follows 20 on the abscissa vertically to the curve for the naphthenic oil degassed at 75° F (24° C) and reads horizontally on the ordinate about 89 percent. Therefore, 89 percent or ten of the eleven tests with the naphthenic oil degassed at 75° F (24° C) had wear rates of 20×10^{-9} grams per meter or lower.

TABLE II. - EFFECT OF DEGASSING PROCEDURE AND PARAFFINIC RESIN ADDITIVE ON VANE WEAR FOR SUPERREFINED NAPHTHENIC MINERAL OIL

Test fluid	Degassing temperature, 24° C			Degassing temperature, 121° C		
	Number of tests	Vane wear, g/m of sliding		Number of tests	Vane wear, g/m of sliding	
		Average	Standard deviation		Average	Standard deviation
Superrefined naphthenic mineral oil	11	123×10^{-10}	21×10^{-10}	12	12×10^{-10}	6×10^{-10}
Superrefined naphthenic mineral oil + 2.25 wt. % paraffinic resin	[a]5	9.2×10^{-10}	3.3×10^{-10}	[a]8	5.7×10^{-10}	6.5×10^{-10}

[a]Average vane wear for all 13 tests with 2.25 wt. % resin, 7×10^{-10} g/m (standard deviation, 5.5×10^{-10} g/m).

A nondegassed naphthenic oil (29 ppm dissolved oxygen) yielded a vane wear rate of about 14.3×10^{-9} grams per meter. This wear value appears as a single point on figure 6 at the 100 percent level for reference.

For oil which did not contain resin additive, the data show that vane wear was substantially lower and more reproducible for oils vacuum degassed at 250° F (121° C) than for oils vacuum degassed at 75° F (24° C). The improvement obtained by higher temperature degassing can be attributed to effective, reproducible reduction of dissolved oxygen to less than 2 ppm during the 250° F (121° C) degassing procedure. Room temperature degassing resulted in a residual dissolved oxygen concentration range of 2 to 20 ppm.

Because the wear rates were very low in the thoroughly degassed oils, it was difficult to determine reliably whether further improvements could be obtained by resin additions. There was an overlap in ranges of wear data for oils with and without the resin additive. However, on the average, a 2.25 weight percent paraffinic resin addition reduced average vane wear to about 1/2 the value obtained in fluids with no resin addition (table II).

The napththenic oil degassed at 75° F and with no resin additive yielded a large scatter in vane wear data. However, with the addition of 2.25 percent paraffinic resin, consistently low wear was obtained with either degassing procedure. One might conclude that the resin had reduced the wear sensitivity to the concentration of initial dissolved oxygen.

Two experiments were run with a 2.25 weight percent resin additive in nondegassed naphthenic oils (37 and 21 ppm initial dissolved oxygen). Higher wear (>23 mg/50 hr test) was obtained in both experiments. Apparently the resin is beneficial only when the initial dissolved oxygen content is less than 20 ppm. Further studies are needed in this area.

Fluid Degradation

The fluids are degraded by a combination of thermal and shear stresses. The thermal conditions are well defined but because of the complex flow in the pump, the shear rate was not determined. Fluid degradation was determined by measuring changes in 100° and 210° F (38° and 99° C) kinematic viscosities, changes in neutralization number, and the filter clogging characteristics. Viscosities and neutralization numbers appear in table III.

All fluids showed little change in viscosity. Neutralization numbers for all fluids were relatively unchanged.

Table IV contains filter clogging data for most of the fluids. As can be seen, the three polyphenyl ether fluids produced large quantities of insolubles as witnessed by the rapid rate of filter clogging. In fact, in order to continue the experiments with the polyphenyl ethers (4P-3E and 5P-4E), the filters had to be completely bypassed after the 35 micron filter was clogged. The naphthenic oil was still operating on the 5 micron filter at test termination. With the larger pore size filters in the system, a greater number of wear particles, as well as insolubles from thermal degradation, would remain in the oil, pass through the pump, and possibly accelerate the wear process. Therefore, vane wear in these fluids was probably higher than it would have been if the oils had been capable of filtration through a 5 micron filter. Nevertheless, it is reasonable to assume that the relative wear rates in the various fluids would still prevail. This is reasonable because the initial wear rates and thermal degradation was higher in these oils which caused the rapid filter clogging in the first place.

TABLE III. - SUMMARY OF MEASURED FLUID PROPERTIES BEFORE AND AFTER TESTING

Test fluid	Test duration, hr	New fluid	Final sample	Percentage of change	New fluid	Final sample	Percentage of change	New fluid	Final sample
		Viscosity at 38° C, cS			Viscosity at 99° C, cS			Amount of KOH per gram, mg	
Superrefined naphthenic mineral oil	150	77.5	77.5	0	8.10	8.10	0	<0.01	<0.01
Superrefined naphthenic mineral oil + 2.25 wt. % paraffinic resin	150	84.0	83.6	-0.4	8.67	8.66	-0.1	<0.01	----
Superrefined paraffinic mineral oil	74	15.3	16.0	4.6	3.36	3.43	2.1	<0.01	0.02
Superrefined paraffinic mineral oil + 5 wt. % paraffinic resin	24.5	19.8	16.1	-19.0	4.00	3.58	-10.0	0.02	<0.01
Superrefined naphthenic (73 wt. %) paraffinic (27 wt. %) mineral oil blend	97	44.9	45.4	1.1	6.10	6.13	0.5	<0.01	----
Superrefined naphthenic (29 wt. %) paraffinic (71 wt. %) mineral oil blend	100	22.3	20.8	-6.7	4.16	3.98	-4.3	<0.01	0.04
Four ring polyphenyl ether	100	66.0	67.3	2.0	6.26	6.33	1.1	<0.01	0.14
Five ring polyphenyl ether	74	359	359	0	13.0	13.1	0.8	0.02	0.19
Modified polyphenyl ether (C-ether)	32	25.2	24.6	-2.4	4.14	4.09	-1.2	<0.01	----

TABLE IV. - FILTER CLOGGING CHARACTERISTICS

FOR VARIOUS FLUIDS

Fluid	Filter mean pore size, μm			
	5	10	20	35
	Time required for filter inlet pressure to exceed 50 psig, hr			
Superrefined naphthenic mineral oil	>150	----	--	--
Superrefined paraffinic mineral oil	6	18	22	>28
Superrefined naphthenic (29 wt. %) paraffinic (71 wt. %) mineral oil blend	25	50	>25	--
Four ring polyphenyl ether	0. 5	10. 5	17	25
Five ring polyphenyl ether	. 5	10	24	30
Modified polyphenyl ether (C-ether)	. 2	2. 5	>29	--
Superrefined naphthenic mineral oil + 2. 25 wt. % paraffinic resin	>150	----	--	--

SUMMARY OF RESULTS

A vane pump loop was used to determine the lubricating ability as well as thermal and shear degradation for a number of high temperature fluid candidates. Fluid temperature was cycled from 425° F (219° C) at the pump inlet to 600° F (316° C) in the fluid heater and back to 425° F (219° C) in the reservoir. An inert cover gas (nitrogen) was maintained in the reservoir. The pump and vanes were made of CVM M-50 tool steel. The major results were:

1. Fluid chemical type and viscosity greatly influenced vane wear. Lowest vane wear was obtained with a 77 centistoke superrefined naphthenic mineral oil. Higher vane wear was obtained with a 15 centistoke superrefined paraffinic mineral oil. Two intermediate viscosity blends of these fluids yielded low vane wear. High wear was obtained with a four-ring and a five-ring polyphenyl ether and a modified polyphenyl ether (C-ether).

2. The mineral oils and mineral oil blends showed no significant fluid degradation (thermal and shear). The three polyphenyl ether fluids produced large quantities of insolubles but viscosities and neutralization numbers were essentially unchanged.

3. The concentration of initially dissolved oxygen in the naphthenic oil had a significant effect on vane wear. Much higher and more erratic wear was obtained in partially degassed oils (2-20 ppm O_2) or nondegassed oils than in thoroughly degassed oil (less than 2 ppm O_2).

4. The addition of 2.25 weight percent paraffinic resin significantly lowered vane wear in the partially degassed oils and had some effect in further reducing the very low wear obtained with thoroughly degassed naphthenic mineral oil. The resin addition to nondegassed oils had no apparent effect on vane wear.

5. High wear was obtained with the polyphenyl ethers over the entire viscosity range studied (1.05 to 1.88 centistokes at 425° F (219° C). Low vane wear was obtained with the mineral oils in the range 1.02 to 1.50 centistokes at 425° F (219° C)). With the mineral oils, a sharp transition to high wear occurred in the lower viscosity range of 0.92 to 1.02 centistokes at 425° F (219° C).

Lewis Research Center,
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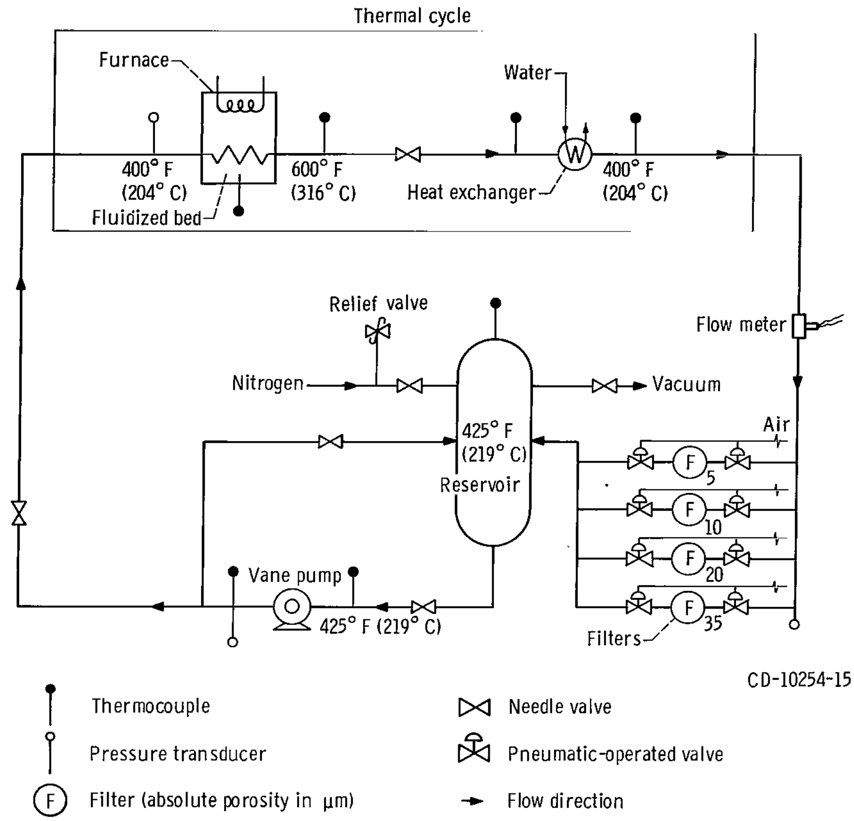

Figure 1. - High temperature fluid loop system.

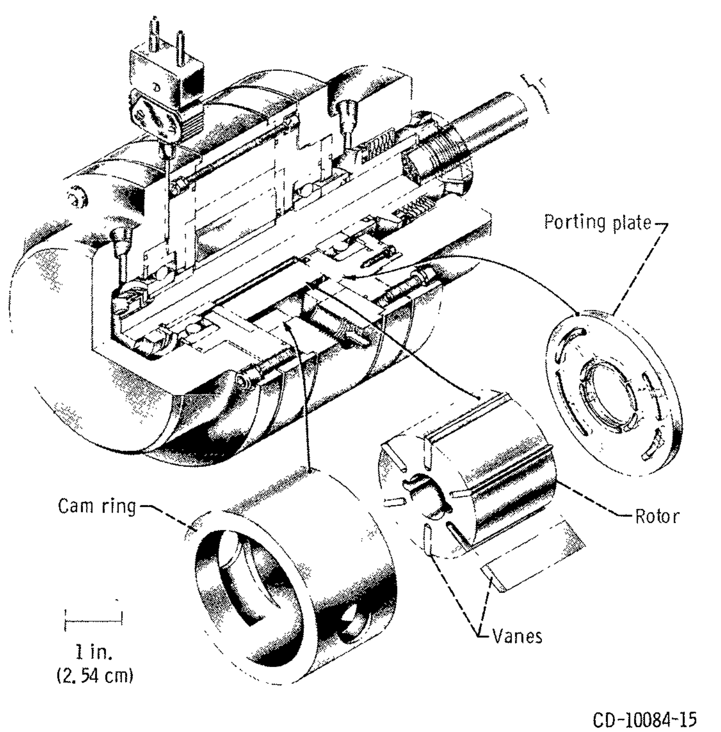

Figure 2. - Vane pump.

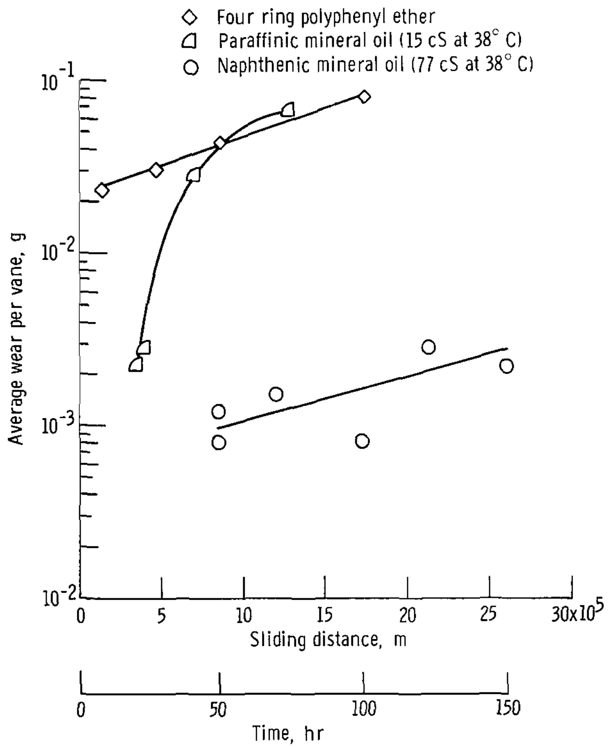

Figure 3. - Average wear per vane as function of sliding distance and time for two mineral oils and a polyphenyl ether. Conditions: pump pressure, 250 psig (1.72×10^6 N/m^2); pump speed, 1600 rpm; bulk fluid temperature, 425° F (219° C); fluids degassed at 250° F (121° C).

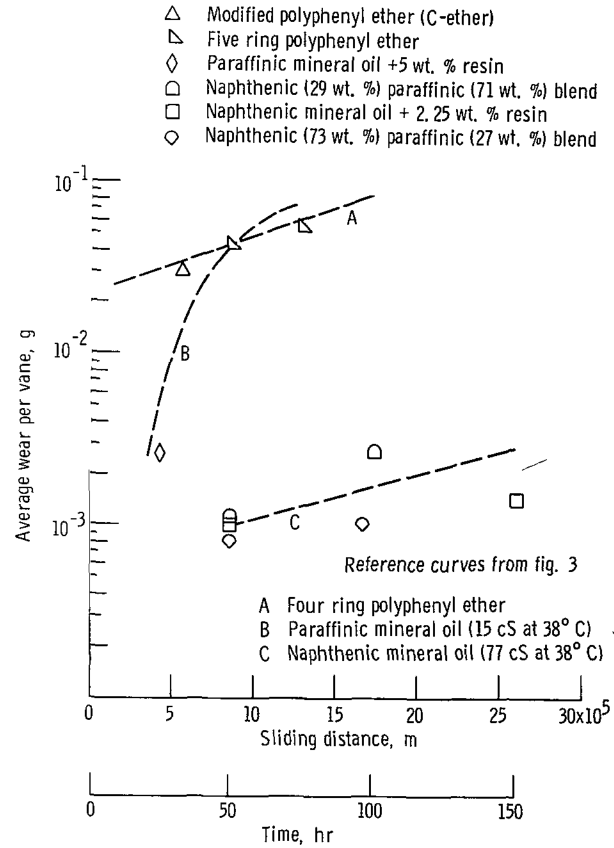

Figure 4. - Average wear per vane as function of sliding distance and time for a number of fluids. Conditions: pump pressure, 250 psig (1.72×10^6 N/m^2); pump speed, 1600 rpm; bulk fluid temperature, 425° F (219° C); fluids degassed at 250° F (121° C).

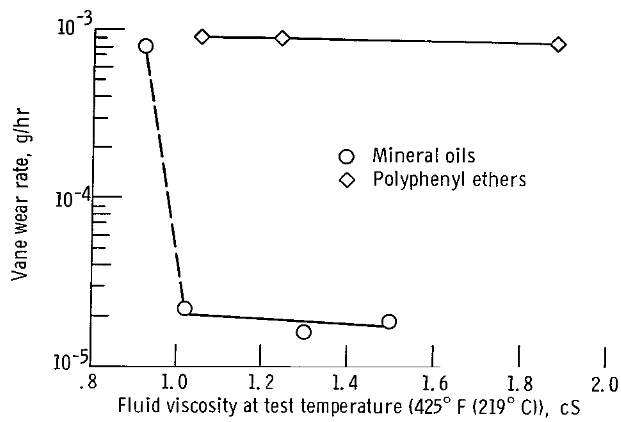

Figure 5. - Vane wear rate as function of fluid viscosity at test temperature. Conditions: pump pressure, 250 psig (1.72×10^6 N/m^2); pump speed, 1600 rpm; bulk fluid temperature, 425° F (219° C); fluids degassed at 250° F (121° C).

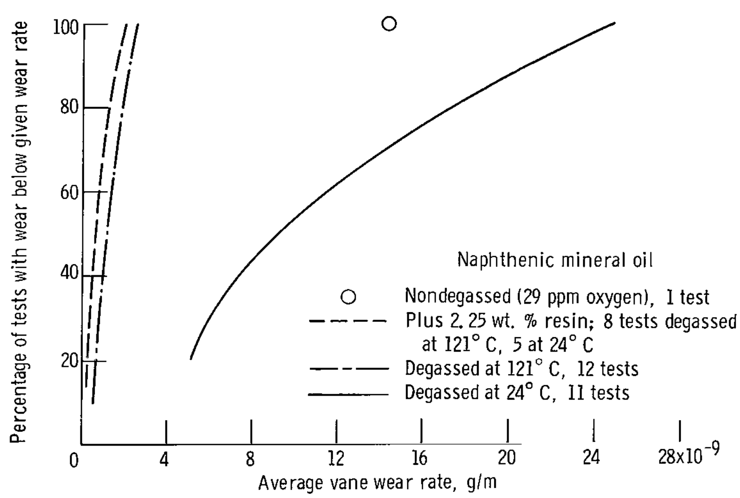

Figure 6. - Cumulative frequency distribution of naphthenic mineral oil vane wear results for two degassing procedures.

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